Does Environmental Decentralization Improve Regional Green Innovation? Evidence from China

Nana Yang (yang916@njupt.edu.cn)
Nanjing University of Posts and Telecommunications
Qiming Liu
Nanjing University of Finance and Economics

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Does environmental decentralization improve regional green innovation? Evidence from China

Nana Yang[a]; Qiming Liu[b*]

([a] High-Quality Development Evaluation Institute, Nanjing University of Posts and Telecommunications, Nanjing, China; [b] School of Public Finance and Taxation, Nanjing University of Finance and Economics, Nanjing, China)

Abstract

Green innovation is critical for sustainable development. The reform of environmental management system plays an important role in improving environmental pollution and technology progress. Working from a heterogeneous perspective, this study investigates the effects of different types of environmental decentralization on regional green innovation using statistical data from 30 provinces in China over the period of 2000–2015. The results show that environmental decentralization (ED) promotes regional green innovation. Furthermore, according to different environmental management of levels and affairs, we divide environmental decentralization into provincial-level environmental decentralization (PED), municipal-level environmental decentralization (MED), and county-level environmental decentralization (CED); environmental administrative decentralization (EAD), environmental monitoring decentralization (EMD), and environmental supervision decentralization (ESD), respectively. There is also evidence suggesting that different types of environmental decentralization have varied effects on regional green innovation. These findings set out in this study are robust when different methods are employed. A further investigation indicates that the effects of different types of environmental decentralization on green innovation apparently differ across Chinese different regions. Some policy recommendations will help policymakers to determine more effective environmental decentralization.

Keywords:

Environmental decentralization; green innovation; environmental management; China

*Corresponding author. E-mail address: 9120201033@nufe.edu.cn (Qiming Liu).

1. Introduction

In recent decades, China achieves a miracle of rapid economic growth due to the adoption of reform and opening-up policies (Hao et al., 2020; Liu and Wang, 2017). After long-term economic growth, China, as the biggest developing country and the second-largest economy in the world, has faced several serious problems such as natural resource depletion and environmental pollution (Bian et al., 2019; Liu et al., 2017; Zhen et al., 2020). Thus, it is urgent to develop innovation capabilities within an environmental context, which can achieve the double-winning goal of environmental and economic benefits (Shen et al., 2020). It is noted that local governments play a vital role in stimulating the development of green innovation, because local governments can provide a better development environment and more effective financial and policy support.

In China, the decentralization reform is an important institutional factor affecting local government behavior (Zhou et al., 2020). For a long time, China was a centralized economy, emphasizing the role of the central government in public affairs. Now, China has become a highly decentralized economy by implementing its fiscal decentralization reforms and environmental decentralization system, therefore, local governments have more management rights in local fiscal and environmental governance (Batterbury and Fernando, 2006). Since 2008, China has been actively promoted environmental decentralization system, that is, the central government gives a lower level of government the corresponding autonomy and responsibilities in environmental management (Fredriksson and Wollscheid, 2014). Currently, local governments can exert their environmental governance rights and implement environmental protection policies in accordance with regional situations. Thus, can environmental decentralization affect green innovation? According to the proposal on the “13th Five-Year Plan”, China has implemented the vertical environmental management system of environmental protection institutions. Therefore, China's environmental decentralization also have been further subdivided. According to different environmental management of affairs, Qi (2014) subdivided environmental decentralization into environmental administrative decentralization, environmental monitoring decentralization, environmental supervision decentralization. There is, however, little valid empirical evidence of the relationship between different types of environmental decentralization and green innovation.

This paper uses the panel data from 30 provinces in China from 2000–2015 to comprehensively estimate the relationship between environmental decentralization and green innovation. There are three main contributions of this study to the ongoing literature. First, we test for the effect of whether environment decentralization affects green innovation. It can enrich and improve the theoretical results of environment decentralization and has important practical significance for environmental governance and green innovation. Second, the effect mechanisms of different types of environmental decentralization are different. In addition to different environmental management of affairs, we divide environmental decentralization into provincial-level environmental decentralization (PED), municipal-level environmental decentralization (MED), and county-level environmental decentralization (CED) according to environmental management of levels. Moreover, this study has made an elaborate analysis of the effects of these different types of environmental decentralization on green innovation. It is favorable for assessing which kind of environmental decentralization can promote green innovation. Third, given the consideration of the imbalance of China's regional economic development, this study divides China into three regions: the eastern, central, and western regions and thereby compares the regional difference of the effect of environmental decentralization on green innovation. It is beneficial to precisely put forward the optimal combination of environmental decentralization targeting different regional green innovation.

The rest of the paper is organized as follows. Section 2 provides the literature review, which reviews the existing research on green innovation and environmental decentralization. Section 3 introduces the evolution and current situation of environmental decentralization in China. Section 4 explains data and estimation methods used in this study. Section 5 presents empirical results and analysis. Section 6 summarizes the conclusion and related policy implications.

2. Literature review

In innovation research, green innovation is an important driving force for regional high-quality economic development by promoting technical progress and transforming regional environments. Green innovation is usually associated with the sustainable development of the ecological environment (Schiederig et al., 2012). Chen et al. (2006) described green innovation as “hardware or software innovation that is related to green products or processes, including the innovation in technologies that are involved in energy-saving, pollution-prevention, waste recycling, green product designs, or corporate environmental management”. The most prominent terms used on similar topics to describe this innovation type are ‘eco-innovation’, ‘environmental innovation’, and ‘sustainable innovation’. Fussler (1996) defined eco-innovations as ‘new products and processes, which provide customer and business value but significantly decrease environmental impacts”. Oltra and Jean (2009) defined environmental innovation as “innovations that consist of new or modified processes, practices, systems, and products which benefit the environment and so contribute to environmental sustainability”. Sustainable innovation is defined as innovation that improves sustainability performance, where such performance includes ecological, economic, and social criteria” (Boons et al., 2013). In this paper, we draw on the work of Kunapatarawong and Martinez-Ros (2016), define green innovation as new processes, techniques and products to avoid or decrease environmental impacts.

Prior research has uncovered various determinants of green innovation from the firm level and region level. At the firm level, green innovation can be driven by both internal and external determinants. While the internal determinants include corporate governance (Amore and Bennedsen, 2016), corporate capabilities (Albort-Morant et al., 2016; Cuerva et al., 2014; Li et al., 2017), executive characteristics (Hao et al., 2019; Ren et al., 2021), literature on green innovation emphasized external determinants such as political capital (Lin et al., 2014), institutional pressure (Chen et al., 2018; Leenders and Chandra, 2013), outward foreign direct investment (Yang, Z. et al., 2020). At the region level, the role of environmental policy tools on green innovation has been explored (Shen et al., 2020), especially environmental regulation (Cai et al., 2020; Dong et al., 2020; Hu and Liu, 2019; Pan, X. et al., 2020; Song et al., 2020). Besides, there is evidence that fiscal decentralization has an effect on green innovation (Zhou et al., 2020).

More recently, environmental decentralization has been a major focus of scholars, the relationship between environmental decentralization and green innovation has also been explored. For example, Feng et al. (2020) examine the relationship between environmental decentralization on green innovation in China for the period of 2006-2015 by the spatial Durbin model. They demonstrate that there exists the local effect and spatial effect of environmental decentralization on green innovation. The findings of the study also indicate that different types of environmental decentralization (environment decentralization of finance and environmental decentralization of government reform) have different effects on green innovation. Based on panel data of 30 Chinese provinces, Zhang and Li (2020) study the relationship between environmental decentralization, environmental protection investment, and green technology innovation and find that environmental decentralization inhibits green technology innovation in the short term, while promotes green technology innovation in the long run.

3. Environmental decentralization in China

Originated from the decentralization system and environmental federalism, environmental decentralization is an environmental management system. In China, environmental management system reform has approximately evolved through three stages (Qi, 2014). The first stage, from 1973 to 1993, established a system of decentralized environmental management and division of administrative power. The second stage run from 1994 through 2007 initially, when environmental management presents centralization characteristics under the decentralized system. The third stage is from 2008 onwards, when the control intensity of central government and environmental governance incentives of local governments have been strengthened under the decentralized system. Thus, in this paper, we describe environmental decentralization as the division of environmental management powers and responsibilities between central and local governments (Wu et al., 2020).

Since 2008, the central government gives local governments more environmental management rights in China. Nowadays, China has established the vertical environmental management system, which combines the central and local governments at different levels of management (Liu et al., 2012). Specially, The Ministry of Environmental Protection (MEP) of the central government is mainly responsible for enacting environmental laws, while local Environmental Protection Bureau (EPB) is responsible for implementing these laws and formulating local environmental regulations that are more suitable for the region. Thus, for local EPBs, they are mainly influenced by local governments rather than the MEP at the central level. Moreover, China's multi-level environmental management system mainly includes four levels: central, provincial, municipal, and county levels. The four-level environmental management agencies belong to the government of the corresponding level (see Figure 1). Figure 2 plots the proportion of staff in environmental management agencies at different levels in China from 2000 to 2015. It can be seen that during 2000-2015, the distribution of staff in environmental management agencies at all levels is basically stable. By computing the 2000-2015 average, we can find that 67.2% of China's environmental management agencies were distributed at the county-level; 24.7% were distributed at the municipal-level; 6.8% were distributed at the provincial-level, and only 1.3% was distributed at the central-level.

In addition to environmental management of levels, environmental management of affairs mainly includes environmental administrative, environmental monitoring and environmental supervision (Qi, 2014). As Zou et al. (2019) have been mentioned, environmental administrative is primarily responsible for formulating local environmental protection policies. These policies are required in accordance with local economic development and the targets of the central government. Environmental monitoring mainly involves monitoring and assessing local environmental quality, while environmental supervision is mainly responsible for environmental law enforcement and supervision. As shown in Figure 3, during the period 2000-2015, 25.45%

of environmental management personnel are engaged in environmental administrative affairs, 28.47% of environmental management personnel are engaged in environmental monitoring affairs, and 29.63% of environmental management personnel are engaged in environmental supervision affairs.

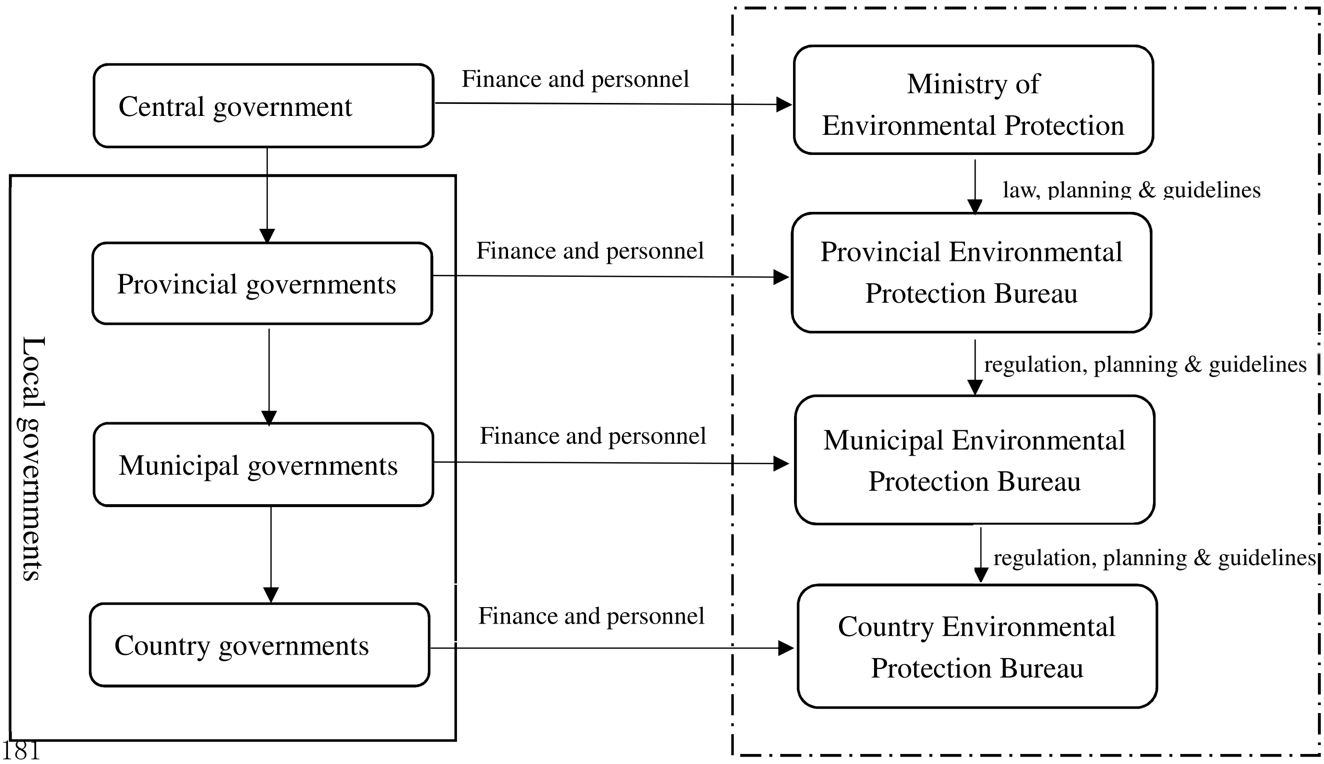

Figure 1 Multi-level environmental management system in China

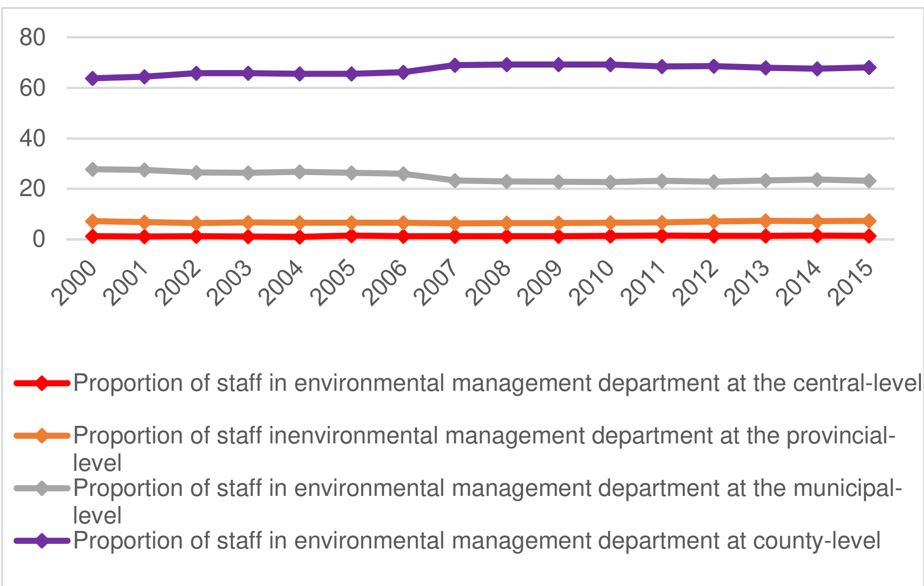

Figure 2 The proportion of staff in environmental management department at different levels

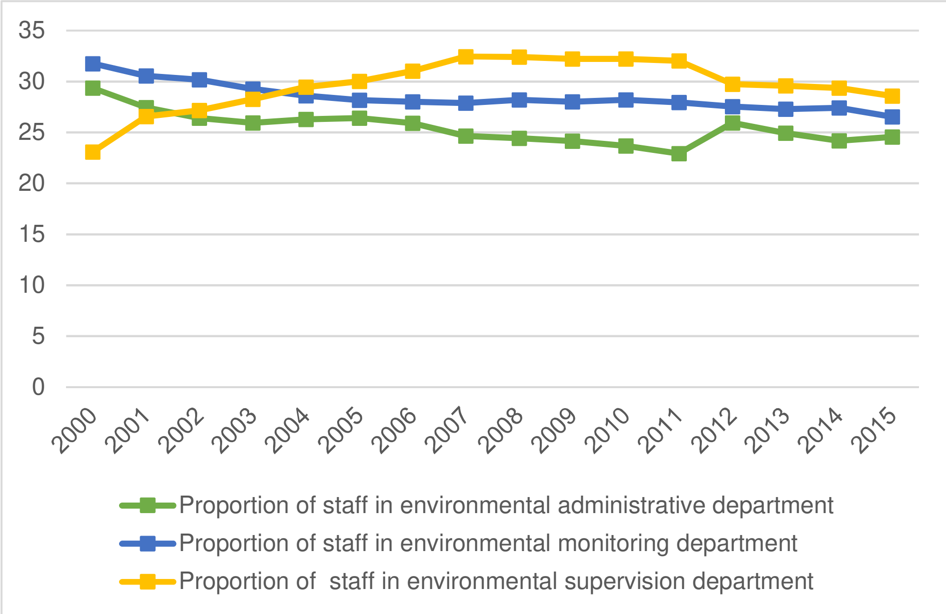

Figure 3 The proportion of staff in different environmental management of affairs

4. Data and empirical methodology

4.1 Data and variables

This study used a panel dataset of 30 provinces from 2000 to 2015. All of the data used come from National Intellectual Property, the China Environment Yearbook, the China Statistical Yearbook on Science and Technology, and the China Statistical Yearbook.

4.1.1 Dependent variable

Green innovation (GI). Previous studies have indicated that the number of green patents is an important measure of China's green innovation (Feng et al., 2020; Pan, X. et al., 2020; Wang et al., 2019; Zhang and Li, 2020). Following Pan, X. et al. (2020) and Zhang and Li (2020), the proxy indicator of GI in this paper is the number of green invention and utility model patent applications, which is determined from environmental technology classified by the World Intellectual Property Organization (WIPO).

4.1.2 Core variables

Environmental decentralization (ED). In line with the current studies, we use the number of central and local personnel within the environmental protection system to measure the degree of environmental decentralization. In addition, according to different environmental management of levels, environmental decentralization includes provincial-level environmental decentralization (PED), municipal-level environmental decentralization (MED), and county-level environmental decentralization (CED). According to different environmental management of affairs, environmental decentralization includes environmental administrative decentralization (EAD), environmental monitoring decentralization (EMD), and environmental supervision decentralization (ESD). The calculation formulae of various types of environmental decentralization are as follows:

$$ED_{it} = \frac{ESP_{it}/POP_{it}}{HSP_t/POP_t} * (1 - GDP_{it}/GDP_t) \quad (1)$$

$$PED_{it} = \frac{PESP_{it}/POP_{it}}{HSP_t/POP_t} * (1 - GDP_{it}/GDP_t) \quad (2)$$

$$MED_{it} = \frac{MESP_{it}/POP_{it}}{HSP_t/POP_t} * (1 - GDP_{it}/GDP_t) \quad (3)$$

$$CED_{it} = \frac{CESP_{it}/POP_{it}}{HSP_t/POP_t} * (1 - GDP_{it}/GDP_t) \quad (4)$$

$$EAD_{it} = \frac{ESA_{it}/POP_{it}}{HSA_t/POP_t} * (1 - GDP_{it}/GDP_t) \quad (5)$$

$$EMD_{it} = \frac{ESM_{it}/POP_{it}}{HSM_t/POP_t} * (1 - GDP_{it}/GDP_t) \quad (6)$$

$$ESD_{it} = \frac{ESS_{it}/POP_{it}}{HSS_t/POP_t} * (1 - GDP_{it}/GDP_t) \quad (7)$$

where HSP_t, HSA_t, HSM_t and HSS_t indicate the national total number of personnel in the environmental protection system, environmental administrative, environmental monitoring, and environmental supervision in year t, respectively. ESP_{it}, $PESP_{it}$, $MESP_{it}$ and $CESP_{it}$ represent the total number of personnel in the environmental protection system, provincial-level environmental protection system, municipal-level environmental protection system, and county-level environmental protection system in year t of region i, respectively. ESA_{it}, ESM_{it} and ESS_{it} represent the total number of personnel in environmental protection administrative, environmental monitoring, and environmental supervision in year t of region i, respectively. POP_t and GDP_t represent the total population and GDP of the country in year t. POP_{it} and GDP_{it} represent the total population and GDP in year t of region i. $1-{GDP_{it}}/{GDP_t}$ is the economic deflator factor to lower the impact of heterogeneity of regional economies of scale.

4.1.3 Control variables

In addition to the main variables, the following variables are selected as the control variables that have a considerable impact on regional green innovation. (1) *R & D input (R&D).* The green innovation of each region is positively related to R&D input, such as R & D expenditures (Luo et al., 2021). The bigger the intensity of R&D input, the stronger the capacity for green technology innovation. This paper uses the proportion of R & D expenditures of a region to GDP as a proxy for the intensity of R&D input. (2) *Financial development (FD).* Financial support is an important source of capital for green innovation, which has significant positive effects in promoting green innovation. Following the previous studies (Zhao et al., 2021; Zhou et al., 2019), the ratio of bank and financial institution loan balance to GDP is used to measure the level of financial development. (3) *Human capital (HC).* The improvement in human capital is conducive to increasing the quality of the workforce in the region, thus improving green innovation. Human capital is determined by the proportion of the population of undergraduate level or above education (Ning et al., 2016). (4) *Marketization level (ML).* According to the work of Zeng et al. (2021) and Zheng (2021), we select the “China marketization index” to evaluate China's marketization level, which is measured in five fields using Principal Component Analysis developed by the National Economic Research Institute (NERI) Reform Foundation.

Table 1 provides the measurements of all variables. Descriptive statistics for variables are reported in Table 2.

Table 1 The measurements of all variables

Variables	Measurement	Data source
Regional green innovation (RGI)	Green invention and utility model patent applications	Intellectual Property Office
Environmental decentralization （ED）	See formulas (1)-(7)	CESY (2000-2015)
R&D input (R&D)	The ratio of R&D expenditures over the regional GDP	CCSY (2000-2015)
Financial development (FD)	The ratio of bank and financial institution loan balance to GDP	CCSY (2000-2015)
Human capital (HC)	The proportion of the population of undergraduate level or above education	CCSY (2000-2015)
Marketization level (ML)	China marketization index	The report of China's Provincial Market Index

Note: CCSY: China City Statistical Yearbook; CESY:China Environmental Statistics Yearbook

Table 2 Descriptive statistics of variables

	Observations	Mean	SD	Min	Max
GI	480	6.037	1.667	0.693	10.01
ED	480	0.975	0.357	0.414	2.29
PED	480	0.027	0.010	0.009	0.059
MED	480	0.032	0.021	0	0.088
CED	480	0.032	0.027	0	0.139
EAD	480	1	0.378	0.378	2.419
EMD	480	1.004	0.369	0.389	2.558
ESD	480	0.945	0.52	0.127	2.53
R&D	480	1.238	1.021	0.146	6.014
FD	480	1.114	0.366	0.537	2.585
HC	480	1.416	0.721	0.213	3.565
ML	480	5.951	1.807	2.37	10.92

4.2 Model specification

In order to explore the effect of environmental decentralization on green innovation, we establish the fixed effects model:

$$LnGI_{i,t} = a_0 + a_1 ED_{i,t} + a_2 X_{i,t} + u_i + \lambda_t + \varepsilon_{i,t} \quad (8)$$

where i , t present the province and year respectively. As the dependent variable, $LnGI_{i,t}$ stands for green innovation. The key explanatory variable ED refers to environmental decentralization. $X_{i,t}$ is a set of control variables that may affect green innovation, including R & D input (R&D), financial development (FD), human capital (HC), and marketization level (ML). In addition, u_i denotes the regional fixed effect, λ_t represents the time fixed effect; ε_{it} signifies the unobserved error term.

5. Empirical analysis results

5.1 Results of national region

Table 3 reports the regression results of the national region. In Table 3, the regression coefficient of environmental decentralization is 0.206, which is significant at 10%, indicating that environmental decentralization has a positive significant impact on regional green innovation. In addition, the regression coefficients of provincial-level environmental decentralization and municipal-level environmental decentralization are 7.033 and 3.807, which are significant at 1% and 10% levels, respectively, while the regression coefficients of county-level environmental decentralization is 3.342 but does not have statistical significance. The results indicate that regions characterized by provincial-level environmental decentralization and municipal-level environmental decentralization have positive impacts on local green innovation. Meanwhile, the regression coefficients of environmental administrative decentralization and environmental monitoring decentralization are significantly positive, whereas the regression coefficient of environmental supervision decentralization is positive but not significant. The results imply that supporting policies involving ongoing supervision that may not have a positive impact on green innovation (Ran et al., 2020).

Table 3 The regression results of national region

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ED	0.206*						
	(1.92)						
PED		7.033***					
		(2.64)					
MED			3.807*				
			(1.70)				
CED				3.342			
				(1.16)			
EAD					0.137**		
					(2.01)		
EMD						0.134*	
						(1.66)	
ESD							0.086
							(1.25)
R&D	0.198***	0.188***	0.185***	0.175***	0.183***	0.184***	0.185***
	(3.55)	(3.50)	(3.40)	(3.24)	(3.38)	(3.38)	(3.34)
FD	0.574***	0.616***	0.602***	0.577***	0.576***	0.586***	0.602***
	(5.95)	(6.50)	(6.33)	(5.86)	(5.99)	(6.12)	(6.31)
HC	0.401***	0.398***	0.373***	0.436***	0.405***	0.395***	0.424***
	(6.42)	(6.38)	(5.66)	(6.50)	(6.48)	(6.28)	(6.63)
ML	0.073***	0.072***	0.075***	0.071***	0.071***	0.075***	0.071***
	(2.80)	(2.76)	(2.84)	(2.69)	(2.71)	(2.84)	(2.70)
Constant	3.040***	3.030***	3.115***	3.153***	3.125***	3.105***	3.146***
	(15.48)	(16.70)	(17.20)	(17.08)	(18.05)	(16.79)	(17.08)
Year dummies	YES	YES	YES	YES	YES	YES	YES
N	480	480	480	480	480	480	480
R-squared	0.961	0.961	0.961	0.961	0.961	0.961	0.961

Notes: t statistics in parentheses. ***, **, * indicates significant at the level of 1%, 5%, and 10%.

5.2 Results of subsample

The development level of Chinese economy is unequal in different regions (Pan, X.F. et al., 2020; Yang, N.N. et al., 2020). To identify the impact of environmental decentralization on green innovation across regions, we classify the total samples into three regions based on their geographical location: eastern region, central region and western region. The eastern region covers 11 provinces and municipalities, referring to Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan provinces. The central region includes 8 provinces, Shangxi, Heilongjiang, Jilin, Anhui, Jiangxi, Henan, Hubei, and Hunan. The western region comprises 11 provinces, municipalities, and autonomous regions, Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shanxi, Gansu, Qinghai, Ningxia and Xinjiang. The estimation results of the three regions are presented in Tables 4-6.

Table 4 The regression results of eastern region

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ED	0.342**						
	(1.99)						
PED		10.464***					
		(2.92)					
MED			7.145***				
			(2.88)				
CED				-3.380			
				(-0.83)			
EAD					0.340**		
					(2.60)		
EMD						0.061	
						(0.57)	
ESD							0.123
							(1.28)
Control variable	YES	YES	YES	YES	YES	YES	YES
Constant	3.478***	3.508***	3.619***	4.067***	3.513***	3.840***	3.763***
	(10.51)	(12.66)	(13.92)	(13.96)	(12.25)	(13.11)	(13.65)
Year dummies	YES	YES	YES	YES	YES	YES	YES
N	176	176	176	176	176	176	176
R-squared	0.974	0.975	0.975	0.973	0.974	0.973	0.974

Notes: t statistics in parentheses. ***, **, * indicates significant at the level of 1%, 5%, and 10%.

As seen in Tables 4-6, the regression coefficients of environmental decentralization, provincial-level environmental decentralization, municipal-level environmental decentralization, environmental administrative decentralization and environmental monitoring decentralization in the eastern region are significantly positive, which is consistent with the national region. Furthermore, the regression coefficients of environmental decentralization, county-level environmental decentralization, environmental monitoring decentralization, and environmental supervision decentralization in the central region are positive and pass the significance test. Finally, the regression coefficient of environmental administrative decentralization is significantly positive in the western region. Note that the regression coefficient of environmental supervision decentralization is negative and passes the significant test at 5% level, indicating that environmental supervision decentralization in the western region has a significant negative effect on green innovation.

Table 5 The regression results of central region

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ED	0.769***						
	(3.47)						
PED		2.726					
		(0.68)					
MED			4.156				
			(0.85)				
CED				16.176***			
				(3.84)			
EAD					0.057		
					(0.48)		
EMD						0.342*	
						(1.87)	
ESD							0.342***
							(2.63)
Control variable	YES	YES	YES	YES	YES	YES	YES
Constant	1.798***	2.336***	2.238***	1.849***	2.443***	2.049***	2.232***
	(4.49)	(5.76)	(5.05)	(4.83)	(6.52)	(4.83)	(6.01)
Year dummies	YES	YES	YES	YES	YES	YES	YES
N	128	128	128	128	128	128	128
R-squared	0.979	0.977	0.977	0.980	0.977	0.978	0.978

Notes: t statistics in parentheses. ***, **, * indicates significant at the level of 1%, 5%, and 10%.

Table 6 The regression results of western region

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ED	0.075						
	(0.33)						
PED		-3.347					
		(-0.50)					
MED			4.954				
			(0.52)				
CED				-0.360			
				(-0.05)			
EAD					0.246**		
					(2.35)		
EMD						-0.199	
						(-1.03)	
ESD							-0.367**
							(-2.28)
Control variable	YES	YES	YES	YES	YES	YES	YES
Constant	3.021***	3.162***	2.975***	3.080***	2.948***	3.228***	3.522***
	(9.20)	(9.31)	(8.62)	(9.29)	(10.19)	(9.91)	(10.17)
Year dummies	YES	YES	YES	YES	YES	YES	YES
N	176	176	176	176	176	176	176
R-squared	0.960	0.960	0.960	0.960	0.961	0.960	0.961

Notes: t statistics in parentheses. ***, **, * indicates significant at the level of 1%, 5%, and 10%.

5.3 Robustness tests

To verify the robustness of previous analysis results, we also perform some additional robustness tests. First, we employ an alternative measurement of regional green innovation. Following Yang, N. et al. (2020) in using invention patent applications to measure innovation, we employ the number of green invention patent applications as a different proxy for green innovation. The results reported in Table 7 remain largely the same.

Then, we remove the economic deflator factor to measure environmental decentralization. The results are reported in Table 8 and demonstrate that the significance and signs of the coefficients for the main variables remain consistent with the above findings.

Finally, we drew on the work of Yu et al. (2021), use spatial panel models to explore the impact of environmental decentralization on regional green innovation. We first conduct the Moran's I test for spatial correlation of regional green innovation and environmental decentralization. Table 9 demonstrates the Moran's I test results, which indicates that regional green innovation and environmental decentralization show a strong positive spatial correlation. Then, following the work of Zang and Liu (2020), we use standardized spatial inverse-distance weight matrix (W) and spatial Durbin model (SDM) to estimate the regression effects, because SDM assumes that both the dependent and the explanatory variables are spatially correlated, which is consistent with the Moran's I test. Table 10 exhibits the estimated results of SDM. The spatial autoregressive coefficient ρ is significantly positive and shows that green innovation from the surrounding provinces affect local green innovation. Although a different estimation method, that is SDM, is employed, we find that the results remain are basically in line with those we obtain from non-spatial settings.

Table 7 Robustness check: alternative measurement of regional green innovation

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ED	0.334**						
	(2.52)						
PED		9.662***					
		(2.92)					
MED			4.684*				
			(1.69)				
CED				0.692			
				(0.19)			
EAD					0.244***		
					(2.90)		
EMD						0.211**	
						(2.10)	
ESD							0.040
							(0.47)
Control variable	YES	YES	YES	YES	YES	YES	YES

Constant	1.758***	1.799***	1.936***	2.092***	1.875***	1.872***	2.060***
	(7.22)	(7.99)	(8.60)	(9.10)	(8.75)	(8.16)	(8.98)
Year dummies	YES	YES	YES	YES	YES	YES	YES
N	480	480	480	480	480	480	480
R-squared	0.949	0.949	0.948	0.948	0.949	0.948	0.948

Notes: t statistics in parentheses. ***, **, * indicates significant at the level of 1%, 5%, and 10%.

Table 8 Robustness check: alternative measurement of environmental decentralization

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ED	0.205**						
	(1.97)						
PED		6.937***					
		(2.72)					
MED			3.892*				
			(1.83)				
CED				3.531			
				(1.28)			
EAD					0.137**		
					(2.06)		
EMD						0.136*	
						(1.73)	
ESD							0.085
							(1.29)
Control variable	YES	YES	YES	YES	YES	YES	YES
Constant	3.035***	3.027***	3.106***	3.143***	3.122***	3.100***	3.143***
	(15.48)	(16.76)	(17.20)	(17.06)	(18.02)	(16.77)	(17.11)
Year dummies	YES	YES	YES	YES	YES	YES	YES
N	480	480	480	480	480	480	480
R-squared	0.961	0.961	0.961	0.961	0.961	0.961	0.961

Notes: t statistics in parentheses. ***, **, * indicates significant at the level of 1%, 5%, and 10%.

Table 9 The Moran's I test results

Year	GI	ED	PED	MED	CED	EAD	EMD	ESD
	Moran's I	Moran's I	Moran's I	Moran's I	Moran's I	Moran's I	Moran's I	Moran's I
2000	0.161**	0.284***	0.297***	0.198***	0.195***	0.379***	0.2***	0.165**
2001	0.199***	0.29***	0.259***	0.113***	0.183***	0.381***	0.214***	0.13**
2002	0.188***	0.317***	0.216***	0.163***	0.177**	0.387***	0.22***	0.216***

2003	0.229***	0.29***	0.221***	0.123***	0.162**	0.342***	0.219***	0.16**
2004	0.212***	0.31***	0.26***	0.121***	0.178***	0.402***	0.191***	0.127**
2005	0.24***	0.288***	0.27***	0.14***	0.155**	0.311***	0.203***	0.122**
2006	0.229***	0.301***	0.273***	0.17***	0.167**	0.32***	0.231***	0.152**
2007	0.271***	0.314***	0.367***	0.151***	0.18***	0.306***	0.229***	0.152**
2008	0.243***	0.335***	0.368***	0.168**	0.174***	0.319***	0.255***	0.161**
2009	0.246***	0.344***	0.291***	0.208***	0.161**	0.294***	0.264***	0.147***
2010	0.243***	0.337***	0.31***	0.204***	0.166**	0.198***	0.285***	0.215***
2011	0.259***	0.341***	0.271***	0.291***	0.165**	0.221***	0.272***	0.208***
2012	0.251***	0.321***	0.274***	0.261***	0.163**	0.239***	0.28***	0.23***
2013	0.25***	0.286***	0.213***	0.275***	0.158**	0.248***	0.292***	0.249***
2014	0.256***	0.262***	0.239***	0.266***	0.153**	0.237***	0.287***	0.256***
2015	0.278***	0.279***	0.219***	0.242***	0.164**	0.303***	0.3***	0.249***

Table 10 Robustness check: a new of regression method

VARIABLES	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
ED	0.293***						
	(3.02)						
PED		8.469***					
		(3.41)					
MED			6.643***				
			(3.36)				
CED				1.989			
				(0.79)			
EAD					0.132**		
					(2.12)		
EMD						0.151**	
						(2.06)	
ESD							0.096
							(1.58)
Control variable	YES	YES	YES	YES	YES	YES	YES
ρ	0.167**	0.179**	0.213***	0.252***	0.212***	0.206***	0.253***
	(2.19)	(2.38)	(2.86)	(3.48)	(2.84)	(2.75)	(3.50)
Province FE	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES
N	480	480	480	480	480	480	480
Log likelihood-be	91.543	91.362	88.594	81.952	87.098	86.080	82.812

Notes: t statistics in parentheses. ***, **, * indicates significant at the level of 1%, 5%, and 10%.

6. Conclusions and policy implications

Using panel data of 30 provinces in China during the period 2000 to 2015, this study examined the effect of different types of environmental decentralization on regional green innovation from a heterogeneous perspective. The conclusions are as follows: Firstly, environmental decentralization can encourage green innovation. Secondly, for different environmental management of levels, the improvement of provincial-level environmental decentralization and municipal-level environmental decentralization can has significant promotional effects on green innovation. For different environmental management of affairs, environmental administrative decentralization and environmental monitoring decentralization have positive impacts on green innovation. Thirdly, the influence between different types of environmental decentralization and green innovation in different regions is different. In the eastern region, we find that regional green innovation is positively correlated with environmental decentralization. It is also correlated with provincial-level environmental decentralization and municipal-level environmental decentralization as well as environmental administrative decentralization and environmental monitoring decentralization. In the central region, environmental decentralization, county-level environmental decentralization, environmental monitoring decentralization and environmental supervision decentralization significantly have positive impacts on regional green innovation. In the western region, only environmental administrative decentralization exerts a positive role in regional green innovation, whereas environmental supervision decentralization negatively affects regional green innovation.

Based upon the conclusions above and the realities of environmental management in China, the following policy implications are provided as follows.

Firstly, environmental decentralization must be encouraged. In China, the central government should actively promote the reforms in the environmental decentralization system, provide local governments with greater autonomy in the use of personnel deployment and capital in environmental protection departments, and enable local governments to rely on their own information advantages of environmental pollution treatment. This action can improve the pertinence and effectiveness of environmental pollution control and make effective use of investment in environmental pollution control to promote green innovation.

Secondly, different environmental decentralization modes must be applied. From the perspective of environmental management levels, provincial-level environmental decentralization and municipal-level environmental decentralization should be improved. For environmental management affairs, local governments should enhance environmental administrative decentralization and environmental monitoring decentralization.

Finally, differentiated environmental decentralization strategies should be formulated in different regions. As the economic development in China's various regions is unbalanced, different environmental decentralization modes have different impacts on green innovation of different regions. The eastern region should strengthen environmental decentralization, provincial-level environmental decentralization, municipal-level environmental decentralization, environmental administrative decentralization and environmental monitoring decentralization. For the central region, environmental decentralization, county-level environmental decentralization, environmental monitoring decentralization, and environmental supervision decentralization should be encouraged. The western region should actively promote environmental administrative decentralization.

This study quantitatively investigates the impact of environmental decentralization on regional green innovation in China and has limitations that could be possible future research directions. Firstly, this study discusses the direct effect of environmental decentralization on regional green innovation, but does not consider a more complicated framework to understand environmental decentralization-regional green innovation mechanisms, such as the threshold effect of environmental decentralization and the moderating effect of fiscal decentralization. Secondly, as regional green innovation activities have spatial autocorrelation (Dong et al., 2020), our research focuses on the impact of environmental decentralization on regional green innovation, but does not consider the importance of spatial spillovers in the explanation of regional green innovation. Future research should consider using spatial econometric models to investigate both the intra and interregional spatial effects between environmental decentralization and regional green innovation.

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Albort-Morant, G., Leal-Millan, A., Cepeda-Carrion, G., 2016. The antecedents of green innovation performance: A model of learning and capabilities. Journal of Business Research 69(11), 4912-4917.

Amore, M.D., Bennedsen, M., 2016. Corporate governance and green innovation. Journal of Environmental Economics and Management 75, 54-72.

Batterbury, S.P.J., Fernando, J.L., 2006. Rescaling governance and the impacts of political and environmental decentralization: An introduction. World Development 34(11), 1851-1863.

Bian, Y.C., Song, K.Y., Bai, J.H., 2019. Market segmentation, resource misallocation and environmental pollution. Journal of Cleaner Production 228, 376-387.

Boons, F., Montalvo, C., Quist, J., Wagner, M., 2013. Sustainable innovation, business models and economic performance: an overview. Journal of Cleaner Production 45, 1-8.

Cai, X., Zhu, B.Z., Zhang, H.J., Li, L., Xie, M.Y., 2020. Can direct environmental regulation promote green technology innovation in heavily polluting industries? Evidence from Chinese listed companies. Science of the Total Environment 746, 140810.

Chen, X.H., Yi, N., Zhang, L., Li, D.Y., 2018. Does institutional pressure foster corporate green innovation? Evidence from China's top 100 companies. Journal of Cleaner Production 188, 304-311.

Chen, Y.S., Lai, S.B., Wen, C.T., 2006. The influence of green innovation performance on corporate advantage in Taiwan. Journal of Business Ethics 67(4), 331-339.

Cuerva, M.C., Triguero-Cano, A., Corcoles, D., 2014. Drivers of green and non-green innovation: empirical evidence in Low-Tech SMEs. Journal of Cleaner Production 68, 104-113.

Dong, Z.Q., He, Y.D., Wang, H., Wang, L.H., 2020. Is there a ripple effect in environmental regulation in China? - Evidence from the local-neighborhood green technology innovation perspective. Ecological Indicators 118.

Feng, S.L., Sui, B., Liu, H.M., Li, G.X., 2020. Environmental decentralization and innovation in China. Economic Modelling 93, 660-674.

Fredriksson, P.G., Wollscheid, J.R., 2014. Environmental decentralization and political centralization. Ecological Economics 107, 402-410.

Fussler, C., 1996. Driving eco-innovation : a breakthrough discipline for innovation and sustainability, in: James, P. (Ed.). Pitman Publishing, London.

Hao, Y., Wang, L.O., Lee, C.C., 2020. Financial development, energy consumption and China's economic growth: New evidence from provincial panel data. International Review of Economics & Finance 69, 1132-1151.

Hao, Y.J., Fan, C.C., Long, Y.G., Pan, J.Y., 2019. The role of returnee executives in improving green innovation performance of Chinese manufacturing enterprises: Implications for sustainable development strategy. Business Strategy and the Environment 28(5), 804-818.

Hu, S.M., Liu, S.L., 2019. Do the coupling effects of environmental regulation and R&D subsidies work in the development of green innovation? Empirical evidence from China. Clean Technologies and Environmental Policy 21(9), 1739-1749.

Kunapatarawong, R., Martinez-Ros, E., 2016. Towards green growth: How does green innovation affect employment? Research Policy 45(6), 1218-1232.

Leenders, M., Chandra, Y., 2013. Antecedents and consequences of green innovation in the wine industry: the role of channel structure. Technology Analysis & Strategic Management 25(2), 203-218.

Li, D., Zheng, M., Cao, C., Chen, X., Ren, S., Huang, M., 2017. The impact of legitimacy pressure and corporate profitability on green innovation: Evidence from China top 100. Journal of Cleaner Production 141, 41-49.

Lin, H., Zeng, S.X., Ma, H.Y., Qi, G.Y., Tam, V.W.Y., 2014. Can political capital drive corporate green innovation? Lessons from China. Journal of Cleaner Production 64, 63-72.

Liu, L., Zhang, B., Bi, J., 2012. Reforming China's multi-level environmental governance: Lessons from the 11th Five-Year Plan. Environmental Science & Policy 21, 106-111.

Liu, Q.L., Wang, Q., 2017. How China achieved its 11th Five-Year Plan emissions reduction target: A structural decomposition analysis of industrial SO2 and chemical oxygen demand. Science of the Total Environment 574, 1104-1116.

Liu, S.X., Zhu, Y.M., Du, K.Q., 2017. The impact of industrial agglomeration on industrial pollutant emission: evidence from China under New Normal. Clean Technologies and Environmental Policy 19(9), 2327-2334.

Luo, Y.S., Salman, M., Lu, Z.N., 2021. Heterogeneous impacts of environmental regulations and foreign direct investment on green innovation across different regions in China. Science of the Total Environment 759(2), 143744.

Ning, L.T., Wang, F., Li, J., 2016. Urban innovation, regional externalities of foreign direct investment and industrial agglomeration: Evidence from Chinese cities. Research Policy 45(4), 830-843.

Oltra, V., Jean, M.S., 2009. Sectoral systems of environmental innovation: An application to the French automotive industry. Technological Forecasting and Social Change 76(4), 567-583.

Pan, X., Cheng, W.Y., Gao, Y.N., Balezentis, T., Shen, Z.Y., 2020. Is environmental regulation effective in promoting the quantity and quality of green innovation? Environmental Science and Pollution Research 28(4), 6232–6241.

Pan, X.F., Li, M.N., Guo, S.C., Pu, C.X., 2020. Research on the competitive effect of local government's environmental expenditure in China. Science of the Total Environment 718, 1-10.

Qi, Y.L., H. Xu, Y, 2014. Research on reformation of China's environmental decentralization system: institutional change,quantitative measurement and effect evaluation China Industrial Economics 01, 31-43.

Ran, Q.Y., Zhang, J.N., Hao, Y., 2020. Does environmental decentralization exacerbate China's carbon emissions? Evidence based on dynamic threshold effect analysis. Science of the Total Environment 721, 137656.

Ren, S.G., Wang, Y., Hu, Y.C., Yan, J., 2021. CEO hometown identity and firm green innovation. Business Strategy and the Environment 30(2), 756-774.

Schiederig, T., Tietze, F., Herstatt, C., 2012. Green innovation in technology and innovation management - an exploratory literature review. R & D Management 42(2), 180-192.

Shen, C., Li, S.L., Wang, X.P., Liao, Z.J., 2020. The effect of environmental policy tools on regional green innovation: Evidence from China. Journal of Cleaner Production 254, 120122.

Song, M.L., Wang, S.H., Zhang, H.Y., 2020. Could environmental regulation and R&D tax incentives affect green product innovation? Journal of Cleaner Production 258, 120849.

Wang, Q.H., Qu, J.S., Wang, B., Wang, P.L., Yang, T.B., 2019. Green technology innovation development in China in 1990-2015. Science of the Total Environment 696, 134008.

Wu, H.T., Li, Y.W., Hao, Y., Ren, S.Y., Zhang, P.F., 2020. Environmental decentralization, local government competition, and regional green development: Evidence from China. Science of the Total Environment 708, 135085.

Yang, N., Hong, J., Wang, H., Liu, Q., 2020. Global value chain, industrial agglomeration and innovation performance in developing countries: insights from China's manufacturing industries. Technology Analysis & Strategic Management 32(11), 1307-1321.

Yang, N.N., Liu, Q.M., Qi, Y., 2020. Does (un)-related variety promote regional innovation in China? Industry versus services sector. Chinese Management Studies 14(3), 769-788.

Yang, Z., Ali, S.T., Ali, F., Sarwar, Z., Khan, M.A., 2020. Outward foreign direct investment and corporate green innovation: An institutional pressure perspective. South African Journal of Business Management 51(1).

Yu, H., Zhiqiang, G., Guanpeng, Y., Haitao, W., Muhammad, I., 2021. The spatial spillover effect and nonlinear relationship analysis between environmental decentralization, government corruption and air pollution: Evidence from China. Science of the Total Environment 763, 144183.

Zang, J.N., Liu, L.L., 2020. Fiscal decentralization, government environmental preference, and regional environmental governance efficiency: evidence from China. Annals of Regional Science 65(2), 439-457.

Zeng, W.P., Li, L., Huang, Y., 2021. Industrial collaborative agglomeration, marketization, and green innovation: Evidence from China's provincial panel data. Journal of Cleaner Production 279, 123598.

Zhang, W., Li, G.X., 2020. Environmental decentralization, environmental protection investment, and green technology innovation. Environmental Science and Pollution Research 24(12).

Zhao, J., Zhao, Z.R., Zhang, H., 2021. The impact of growth, energy and financial development on environmental pollution in China: New evidence from a spatial econometric analysis. Energy Economics 93, 104506.

Zhen, H.F., Hu, H., Xie, N., Zhu, Y.Q., Chen, H., Wang, Y., 2020. The heterogeneous influence of

economic growth on environmental pollution: evidence from municipal data of China. Petroleum Science 17(4), 1180-1193.
Zheng, W., 2021. Effects of China's market-oriented economic reform, FDI inflows on electricity intensity. Energy 220, 119934.
Zhou, C.Y., Hong, J., Wu, Y.R., Marinova, D., 2019. Outward foreign direct investment and domestic innovation performance: evidence from China. Technology Analysis & Strategic Management 31(1), 81-95.
Zhou, K., Zhou, B.C., Yu, M.M., 2020. The impacts of fiscal decentralization on environmental innovation in China. Growth and Change 51(4), 1690-1710.
Zou, X., Lei, C., Gao, K.Y., Hu, C., 2019. Impact of Environmental Decentralization on Regional Green Development. Journal of Environment & Development 28(4), 412-441.